USAASTA PROJECT NO. 68-55

FLIGHT EVALUATION COMPLIANCE TEST TECHNIQUES FOR ARMY HOT DAY HOVER CRITERIA

FINAL REPORT

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UNITED STATES ARMY AVIATION SYSTEMS TEST ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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Tests were conducted by the United States Army Aviation Systems Test Activity to determine test procedures to be used for compliance verification of the Army's hot day hover criteria. The effort consisted of determining the procedures for vertical climb and yaw maneuverability tests and recommending the compliance test procedure. The flight testing was primarily conducted with an AH-1G helicopter at Edwards Air Force Base and the Naval Weapons Center at China Lake,

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A

20. Abstract

California from November 1970 through September 1971. The test results show that both vertical climb testing and yaw maneuverability testing involve limiting factors which result in uncertainty in the data. A test procedure was developed to demonstrate the yaw maneuverability and calculate the vertical climb capability, utilizing tethered hover test techniques to reduce the data uncertainty. This recommended procedure provided results which were in good agreement with the flight test results and should be adequate for determination of the hot day hover performance margin.

PREFACE

Technical and data gathering support was provided by the Naval Weapons Center, China Lake, California for the quantitative phases of the project. During the evaluation of the pilot's ability to perform vertical climbs, space positioning support was provided by the Air Force Flight Test Center, Edwards Air Force Base, California. In addition to those by the project pilot, test flights were also accomplished by Mr. Joseph Watts, Major Ronald Holasek, CW-3 John Thomson, and CW-2 Roscoe Souders. Initial data reduction and analysis were provided by Mr. Dominick Lubrano, Mr. Raymond Smith, and Mr. Robert Kyker. The final data analysis and report were prepared by Mr. Edward Bailes, Captain Louis Kronenberger, and Mr. Barclay Boirun.

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INTRODUCTION

BACKGROUND

1. The out-of-ground effect (OGE) design hover criterion of 6000 feet, 95°F, has been used in the procurement of Army helicopters with only a few exceptions since the mid-1950's. The lack of a substantive basis for this design point has resulted in questioning as to the need for such a standard. In recent years, this questioning has resulted in a lowering of the standards to 5000 feet, 90°F, and 4000 feet, 95°F, in the draft Qualitative Materiel Requirements (QMR) and Qualitative Materiel Design Objectives (QMDO) of a number of proposed systems.

2. Regardless of the atmospheric conditions, a design criterion that requires only maximum OGE hover capability is somewhat misleading, in that there is not sufficient power available at the hover ceiling to accomplish any required maneuvers. Additional power is needed to accelerate, maneuver, or perform a vertical climbout. Studies were undertaken by the United States Army Combat Developments Command (CDC) (ref 1, app A) and the United States Army Aviation Systems Command (AVSCOM) (ref 2) to determine what power margin is required and how it should be specified. Based on the results of these studies, the current Department of the Army hot day design hover requirement is stated in reference 3, as follows:

> The aircraft shall be capable of hovering out of ground effect (OGE) at its design or primary mission gross weight; under zero wind, 6000 feet pressure altitude, 95°F; and achieve a 500-foot per minute vertical climb at zero airspeed under these conditions, using military rated power.

However, the design ambient conditions were stated as a goal and several recent exceptions were made by the Department of the Army Staff. Most notable were the reduction to 4000 feet and 95°F requirement for the utility tactical transport system (UTTAS) and advanced attack helicopter (AAH).

3. The AVSCOM proposed in reference 2, appendix A, that the 500-foot per minute (ft/min) vertical climb rate requirement could be replaced by the OGE hovering directional controllability criterion contained in military specification MIL-H-8501-A (ref 4) when conducted at the hot day conditions. The recommended AVSCOM specification is stated as:

The rotor craft shall be capable of hovering out of ground effect (OGE) at its design or primary mission gross weight with pressure altitude and temperature conditions of 6000 feet, 95°F, using normal rated power. At this hover ceiling the rotorcraft must also achieve following a full directional control input, a yaw angular displacement in either direction from trim in 1 second of $330/(GW + 1000)^{1/3}$ degrees, where GW is the gross weight in pounds.

The reason for this proposed change was the belief that the directional controllability criterion could be more accurately tested, and that compliance would still yield the desired performance margin.

4. In November 1968 AVSCOM requested the United States Army Aviation Systems Test Activity (USAASTA) to conduct a comparative flight evaluation of the accuracies that could be attained in measuring vertical climb performance and yaw maneuverability in a hover (ref 5, app A). The USAASTA completed this evaluation using a tandem rotor CH-47C helicopter, and prepared a letter report for AVSCOM (ref 6) which indicated that the excess power required to demonstrate the maneuverability requirement was negligible on the aircraft tested. The accuracy of the data from a single 500 ft/min climb was about ±50 percent and thus many climbs and statistical methods would be needed to determine the performance. The AVSCOM review determined that additional testing was required to evaluate single rotor helicopters and to obtain more quantitative data for vertical climb and directional controllability. On 27 November 1970, USAASTA received an AVSCOM directive to prepare a new test plan for the additional testing (ref 7).

TEST OBJECTIVES

5. The objectives of the hot day hover performance criterion testing were as follows:

a. To determine the degree of accuracy and repeatability which is possible in measuring vertical climb performance and yaw angular displacement.

b. To compare power requirements for vertical climb performance and angular displacement.

c. To evaluate the relative merit of these test criteria as performance demonstration requirements, and recommend a test technique.

TEST SCOPE

6. Quantitative studies of the power requirements to perform vertical climb and yaw control power tests were conducted at the China Lake Naval Weapons Center (NWC), China Lake, California, using NWC optical space positioning instrumentation. The tests were accomplished with an AH-1G (Cobra) helicopter. The vertical climb tests were conducted at gross weights between 7200 and 8000 pounds at a mid center-of-gravity (cg) location. The average density altitude was 2200 feet, and the nominal rotor speed was 324 rpm. Approximately 5 hours of productive flight time were used for the testing at NWC.

7. The tests conducted at Edwards Air Force Base, California, consisted of both quantitative and qualitative evaluations of the pilot's ability to fly and evaluate the vertical climb and yaw control power test maneuvers. Two additional single-rotor helicopters (the OH-6A and UH-1M) and five test pilots with varying degrees of experience were used to obtain statistical data during vertical climbs. However, performance data from these helicopters were not included since test instrumentation was not installed. The last test was yaw maneuvers with the AH-1G helicopter tethered at a 50-foot height. Approximately 16 hours of productive flight time were expended during the portion of the testing at Edwards.

TEST METHODOLOGY

8. The methods of test were presented in the test plan (ref 8, app A) and are summarized below.

Vertical Climb Accuracy

9. The vertical accuracy test was a study of a pilot's ability to perform a vertical climb from an OGE hover. A qualitative portion of this phase determined how accurately a pilot could judge the vertical component of his flight path. The quantitative portion was a statistical study of the deviation from the vertical climb as a function of the pilot, aircraft, and amount of power applied. Pilot comments concerning the flight path and any influencing factors were recorded. Data were recorded as the pilot became more proficient so as to evaluate the pilot's "learning curve." The major factors recorded for the quantitative portion included winds, aircraft type, pilot experience, ground reference, and fatigue. The same test site was used throughout the testing, and each pilot flew a series of test points in each of the three aircraft. The maximum allowable surface winds were 5 knots. A tethered balloon was used to provide a vertical reference to the pilots. Space positioning information was obtained from data recorded by two theodolites.

Nonvertical Climbs

10. Preliminary evaluations showed that pilots generally recognized deviations from the vertical, but that there was time to apply only one correction within the test altitude range. Therefore, the initial tests flown at the NWC had two parts. The

first part was a quantitative evaluation of the effects of a constant deviation from the vertical and the second was a quantitative evaluation of a nonvertical flight path where one correction toward the vertical was made. The pilot first climbed at 5, 10, and 15-degree deviation angles from the vertical using a constant power setting. The three different deviation angles were flown in four directions (forward, backward, and towards each side). The highest number of test points were forward and to the right. Each climb was initiated and maintained by a collective step input. In the second test, the climb was started at an angle and then the pilot made a correction toward the vertical.

Vertical Climb Performance

11. To conduct the performance tests, vertical climbs of approximately 20 seconds duration were made from OGE hover at various constant collective settings. The amount of each collective input was controlled by use of a fixture place on the copilot collective stick. The rates of climb achieved ranged from 400 to 1000 ft/min with the greatest density of test points being around 1000 ft/min. The space positioning data were used to obtain the rate of climb and deviation from vertical. Performance parameters were recorded on an oscillograph.

Directional Controllability During Free Flight Hover

12. In these directional controllability tests, the pilot initiated a pedal input while in an OGE hover and held the input for approximately 2 seconds. The resulting horizontal and vertical translation were measured by Bowen cameras at the NWC. Angular yaw displacement and time were obtained from the photographs obtained from a vertically positioned Bowen camera. The tests were flown at gross weights between 6500 to 7000 pounds, and a rotor speed of 324 rpm.

Directional Controllability During Tethered Hover

13. This test was an evaluation of the acceptability and advantages of performing directional controllability tests during a tethered hover. The aircraft was tethered at a 50-foot skid height. The pilot used the same test techniques as stated in paragraph 12. While in the hover, the torque setting was such that approximately 1000 pounds of tension was maintained on the cable. The cable tension was to ensure that the aircraft would not descend should a thrust loss result from the directional control input. The tethering mechanism had a quick release at the aircraft for emergency purposes.

RESULTS AND DISCUSSION

GENERAL

14. Statistical data were obtained to determine the pilot's ability to perform accurate vertical climbs in various models of Army helicopters. This evaluation showed that vertical climbs within an allowable deviation angle could be flown with satisfactory repeatability and that each pilot's proficiency significantly improved with experience in the maneuver. The measured climb data showed considerable scatter and energy corrections for nonsteady flight conditions were employed to improve the results. The excess power required for moderate rates of climb was small. The engine power instrumentation was not sufficiently accurate, which required that a substantial number of data points be generated and an extensive analysis be used to develop suitable climb performance results.

15. A momentum analysis method was developed to predict the vertical climb performance on the basis of hover power required. The predicted value was sufficiently accurate at rates of climb below 8.3 feet per second (500 ft/min). At higher values, the prediction became increasingly optimistic and requires a test-derived correction factor to obtain desired accuracy. The power required for yaw maneuverability was investigated by free-flight and tethered hover methods. From an instrumentation and aircraft positioning standpoint the tethered hover method is preferable. The tethered hover method dictates one less degree of aircraft freedom, eliminates the need for sophisticated space positioning equipment, and main rotor thrust is measured directly with a load cell. Energy losses due to nonvertical motion are also minimized. The test data and analytical calculations show that for the AH-1G, more excess power would be required to meet the yaw displacement requirement than to climb at 500 ft/min. However, this power is only required for a short period of time and is transient in nature.

16. The recommended test procedure is to determine the excess power or thrust available from tethered hover data and calculate the vertical rate of climb from adjusted momentum analysis. If required, the basic momentum analysis data line could be corrected to match a best fit test data line by determining a climb power correction factor. Also, parameter extrapolation to specified conditions can easily be made by loading the cable and varying rotor speed until the corresponding tip Mach number and thrust coefficient are attained.

VERTICAL CLIMB CRITERION

Vertical Flight Path Accuracy

17 During the testing five pilots of varying experience and training were used in the UH-1M, AH-1G, and OH-6A helicopters to evaluate the capability to accomplish a vertical climb. Results show that the pilots tended to climb at some

initial angle and then, recognizing it was not vertical, make corrections toward the vertical. The performance of pilots who were not experienced in vertical climb testing improved rapidly during the initial portion of the test. Following this familiarization phase, there was no appreciable difference in vertical-climb accuracy between any of the pilots. Figure A shows the mean performance achieved by all the pilots in the different aircraft tested. The figure illustrates the difficulty in maintaining small flight path angle deviations from the vertical. If small flight path angle deviations are specified, extensive flight time will be be required to obtain a statistically significant sample.

Vertical Climb Angle

18. During the second phase of the vertical climb tests it was planned to determine the effect of climb angle (γ) on vertical climb performance. These tests showed, however, that it was not possible to repeatedly select and maintain a given climb angle. Therefore, it was not possible to determine climb angle effects on performance from the test data. Because these data could not be obtained, an analytical approach was used to assess the excess power required to climb. Figure B shows power required versus airspeed obtained in low-speed translational flight for a UH-1M helicopter. It is seen that the power decreases approximately 10 to 15 horsepower per knot at airspeeds above 3 knots. Since the accuracy of the installed power instrumentation during these tests was approximately ±30 engine shaft horsepower (eshp), a value of ±3 knots was established as the maximum acceptable horizontal speed component for these tests.

19. Figure C illustrates the geometric relationship between the flight path deviation angle (γ), the ground track azimuth (ψ), and the vertical and horizontal velocity components (V_v and V_h respectively). In table 1 the flight path deviation angle is calculated for vertical rate of climb (VROC) values between 500 and 3000 ft/min based on the horizontal airspeed component (V_h) of 3 knots. It is noted that the high rates of climb require correspondingly small flight path deviation angles and that the probability of being within these constraints is reduced. Also shown in table 1 is the probability of performing a vertical climb with less than the stipulated limit climb angle. These probabilities were determined from figure A. A high probability of conducting the low vertical rate of climb tests within the acceptable accuracy limitations is evident. On the basis of the test conducted herein, near-vertical, 500 ft/min climbs can be flown with acceptably low horizontal velocity components.

FIGURE A

FLIGHT PATH ANGLE DEVIATION IN VERTICAL CLIMB

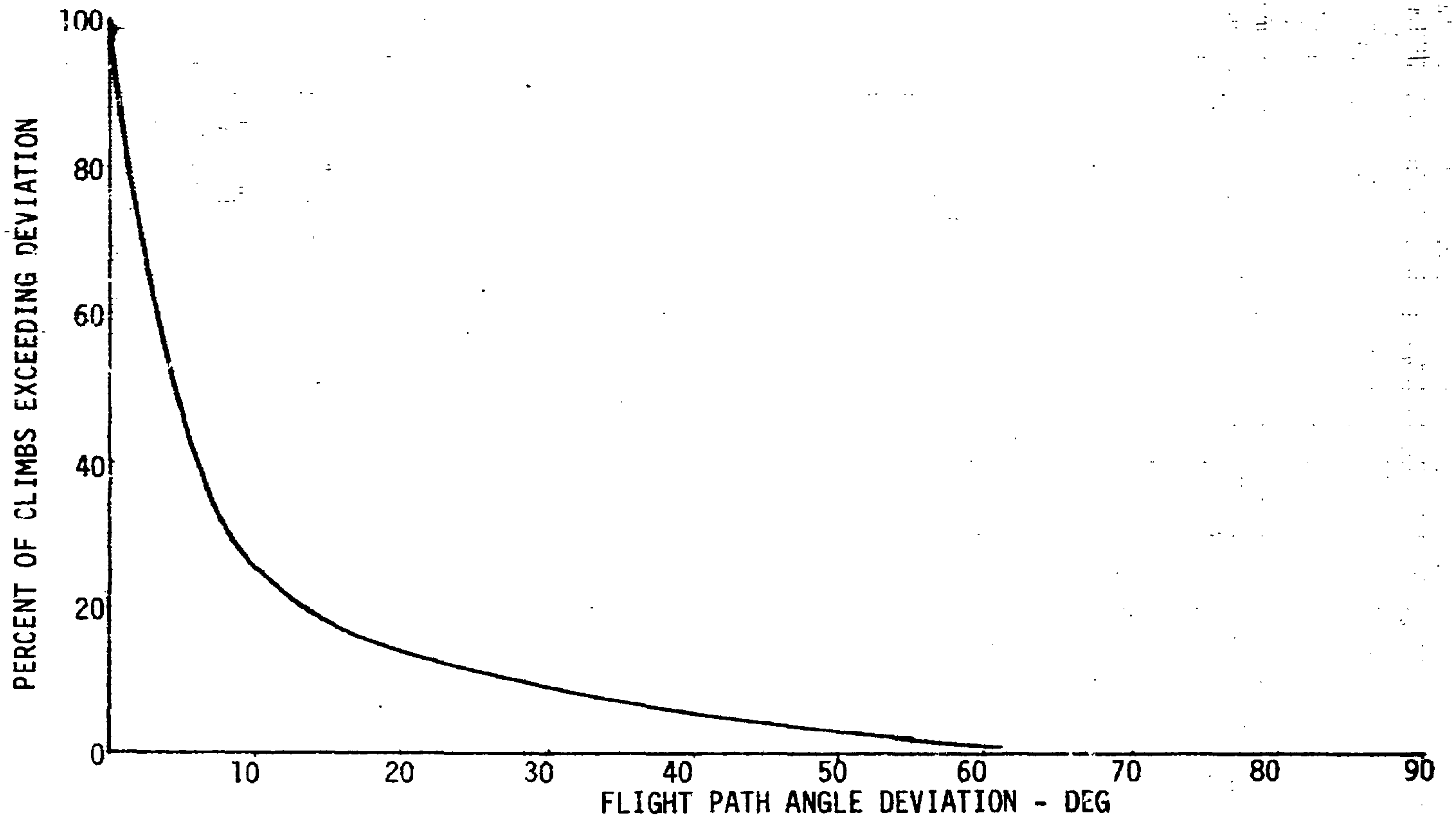


FIGURE 8
POWER REQUIRED IN LOW-SPEED FLIGHT
UH-1M USA S/N 63-8684

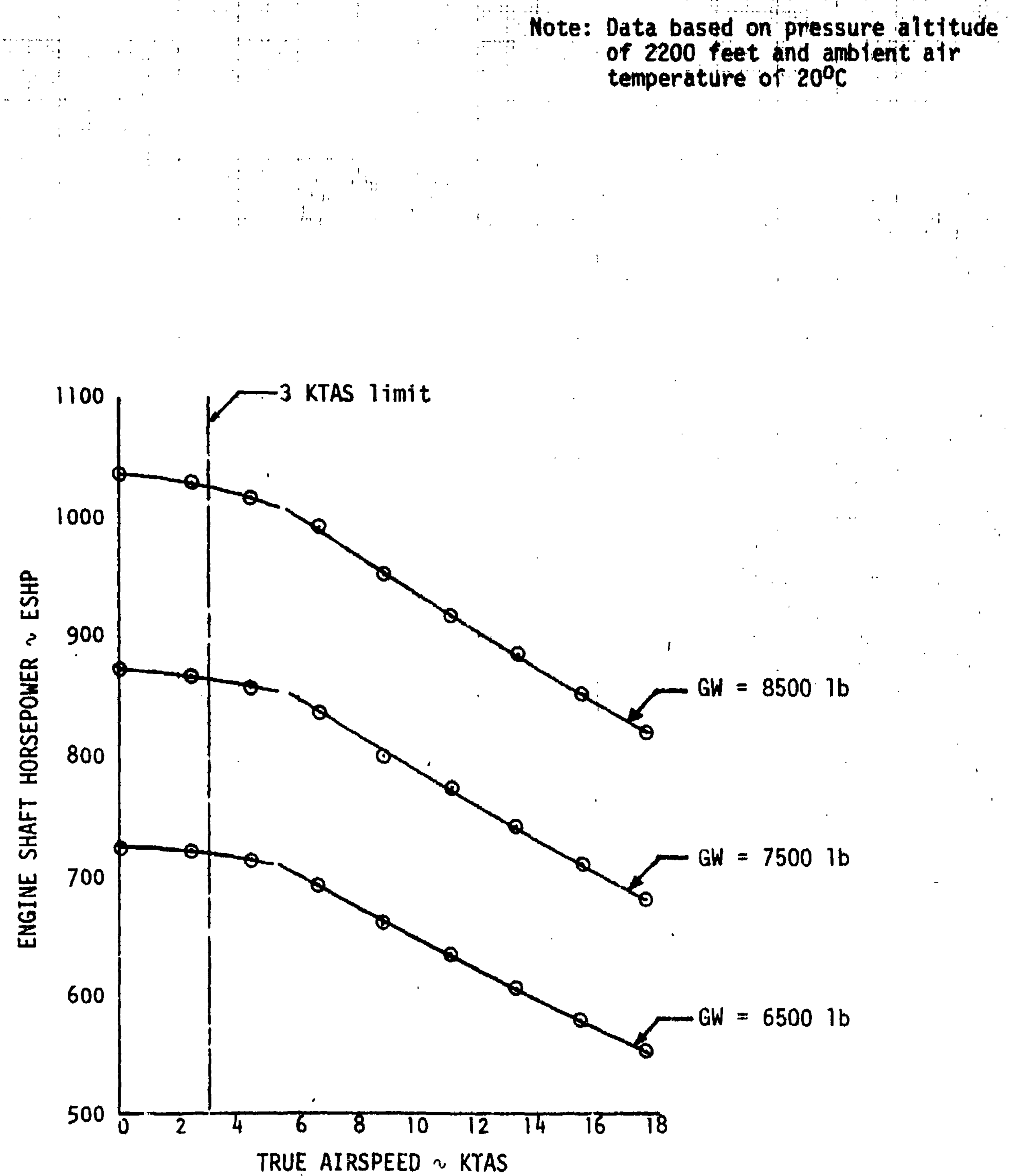


Figure C. Vertical Climb Geometry

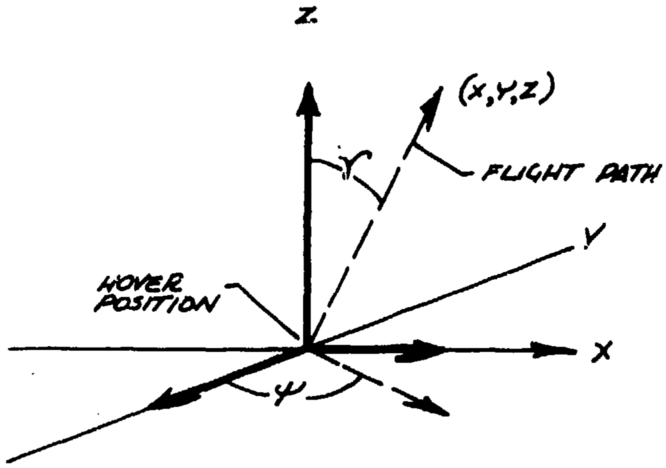


Table 1. Vertical Climb Angle Limitations.

Vertical Rate of Climb[1]		Climb Angle[2] (deg)	Number of Test Points Within Limit (%)
Feet per Minute	Feet per Second		
500	8.3	31.3	91
1000	16.7	16.9	84
1500	25.0	11.5	77
2000	33.3	8.6	71
2500	41.6	6.9	65
3000	50.0	5.8	60

[1]Vertical rate of climb (V_v) - ft/sec.
[2]Climb angle: $\gamma = \mathrm{Tan}^{-1} (V_h/V_v)$, where $V_h = \pm 5.05$ ft/sec.
[3]Data obtained from statistical data for all pilots, aircraft, and flight conditions as shown on figure A.

Vertical Climb Performance

20. Typical results of a vertical climb performance test conducted at the NWC space positioning range are summarized in table 2, and figure D. Variations in gross weight, rotor speed, climb angle, and atmospheric conditions were unavoidable. The energy corrections discussed in appendix B were applied to compensate for these variations. These energy corrections considerably reduced scatter in the measured data and are essential for obtaining good results. The corrected data for the hover preceding the climb was compared to AH-1G hover performance data in reference 9, appendix A, to ensure validity of each test point. Due to the wide variation of gross weight, the climb and hover power at each test point were also corrected to the average weight of the test data to account for potential energy variation. These corrections were derived from the AH-1G hover performance curve and basic momentum analysis discussed in appendix D. In the future, VROC performance tests should be flown at either constant referred or nondimensional test conditions to simplify data reduction and improve parameter extrapolation. The remaining data uncertainty of approximately ±240 ft/min is primarily a result of the instrumentation accuracy which is discussed in appendix C.

Table 2. Vertical Climb Performance Data.[1]

Test Point	Gross Weight (lb)	Flight Path		Wind Speed (kt)	Measured Hover Power (eshp)	Energy Corrected Hover Power (eshp)	Energy Corrected Climb Power (eshp)	Climb Power Adjusted to Avg Gross Wt[3] (eshp)	Excess Power Adjusted to Avg Gross Wt[4] (eshp)	Final Vertical Rate of Climb (ft/min)
		Azimuth[2] (deg)	Climb Angle (deg)							
2	7680	36	3	<1	876	873	1028	1012	154	882
4	7620	-168	14	<1	883	885	1040	1036	155	1188
5	7590	-30	15	<1	907	887	1075	1077	188	1296
6	7570	-140	2	<1	920	872	1035	1041	164	1008
8	7500	-34	14	<1	903	887	995	1014	109	774
9	7480	9	10	<1	872	857	980	1002	125	960
10	7465	0	7	<1	904	860	985	1010	127	972
11	7450	-15	13	<1	872	870	956	984	87	600
12	7430	-19	12	<1	871	859	942	973	85	816
13	7410	9	7	<1	871	862	992	1028	133	960
14	7390	3	3	<1	869	842	988	1028	150	1062
15	7380	-4	2	<1	876	834	1018	1061	188	1200
18	7290	14	6	<1	840	801	985	1044	215	1206
19	7290	17	4	<1	843	833	1041	1102	217	1410
20	7250	37	2	<1	845	800	1025	1094	235	1500
23	7940	180	3	1	954	944	1107	1041	155	1044
24	7920	-165	6	2	911	903	1123	1060	211	1248
25	7900	-38	3	1	939	926	1174	1113	239	1440
26	7880	0	7	<1	943	909	1063	1009	147	864
27	7860	57	6	<1	900	874	1081	1030	200	870
28	7840	16	4	<1	922	920	1038	993	114	942
29	7820	124	19	<1	868	852	1003	962	146	588
30	7800	110	5	2	944	956	1002	964	44	396
31	7720	-118	8	5	842	843	911	890	67	402
32	7700	-158	5	10	864	864	960	942	95	516

[1]Average flight conditions:
Rotor speed: 324 rpm.
Gross weight: 7600 pounds.
Pressure Altitude: 2200 feet.
Ambient Temperature: 20°C.

[2]Azimuth positive for right crosswinds.

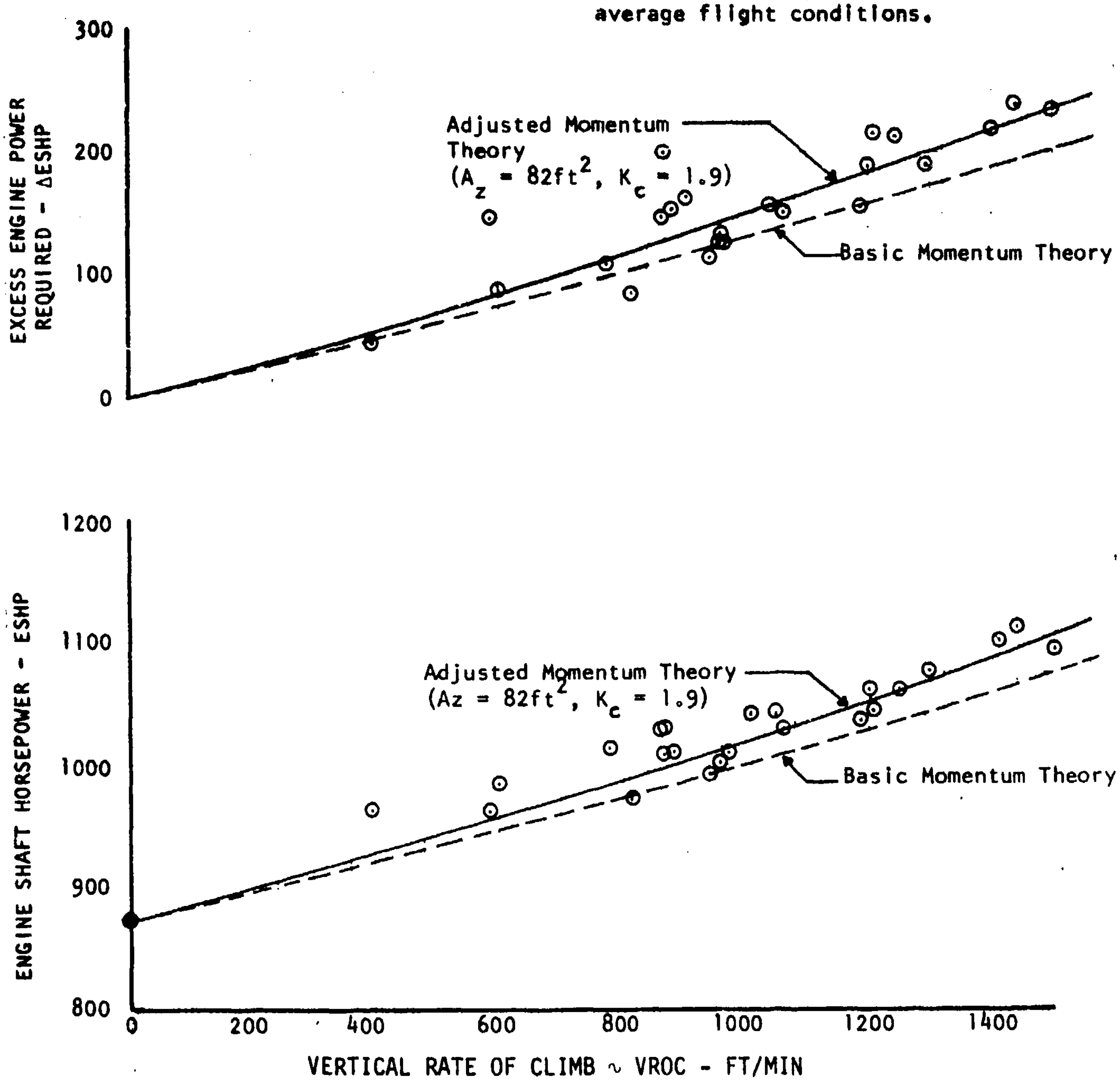
[3]Power adjustment to average gross weight: $P_c \times (\frac{7600}{GW})(1.5-.000835\ VROC)$.

[4]Excess power adjustment to average gross weight: $P_{ex} \times (\frac{7600}{GW})$.

FIGURE D
VERTICAL CLIMB PERFORMANCE
AH-1G USA S/N 69-16410

SYMBOL	AVG GROSS WEIGHT (LBS)	AVG PRESSURE ALTITUDE (FEET)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
⊙	7600	2200	20	324

NOTES: 1. Shaded symbol represents average power for all test points.
2. Test data corrected for weight variation from average.
3. Momentum analysis based on average flight conditions.



21. Figure D presents VROC performance data for the AH-1G in terms of total engine power and the excess power to climb from a hover. The measured engine power was corrected for energy variations and then adjusted to a mean gross weight of 7600 pounds, as shown in table 2. This data indicates that the AH-1G at 7600 pounds gross weight would require an excess engine power of about 60 eshp to climb 500 ft/min at the average test conditions. The basic VROC performance momentum analysis discussed in appendix B showed good agreement with the test data at rates of climb of 500 ft/min and below. Above 500 ft/min, this analysis was increasingly optimistic with vertical speed. Therefore, a power correction factor was determined to adjust the basic theory to fit the best data line through the test data. The corrective procedure is discussed in appendix B and required the empirical determination of the slope of the power error (K_C) as a function of the vertical advance ratio ($V_V/\Omega R$). The K_C factor may be utilized as a VROC power correction factor; however, the limited data available on this test may be insufficient for determining the optimum corrective procedure.

Vertical Climb Time History

22. A time history of test point 13 from table 2 is shown in figure E. The climb was initiated at -1.5 seconds and the steady rate-of-climb point was measured between 14 and 16 seconds. The flight data are shown in comparison to a 1-degree-of-freedom vertical climb model, discussed in appendix B. The model was run with a 2-second time delay for thrust build up which was obtained from the flight data. In general, the model does a good job of predicting the vertical flight parameters. The oscillations in the actual vertical acceleration data were due to varying rotor speed and horizontal accelerations which are not accounted for in the model. Comparison of the flight data to this simple model indicated that both moderate vertical climb rates and the vertical flight profile can be accurately predicted.

Recommended Test Technique for Vertical Climb Criterion

23. Table 3 presents the various aspects of vertical climb testing. The following test technique is recommended based on experience gained during the vertical climb portion of this test program. It considers equipment capabilities, available methodology, test time required, pilot capabilities, safety, data processing, support requirements, and instrumentation accuracies.

a. Test to establish base-line nondimensional OGE hover performance at tip mach numbers of interest.

b. Perform sufficient VROC tests on each required configuration to establish a power correction factor with which to adjust momentum analysis to best fit the actual test data.

c. Compute VROC specification compliance at the specified hot day conditions using the base-line hover OGE performance data and the adjusted momentum analysis determined from the VROC tests.

FIGURE E
TIME HISTORY OF VERTICAL CLIMB FLIGHT PATH PARAMETERS
AH-1G USA S/N 69-16410

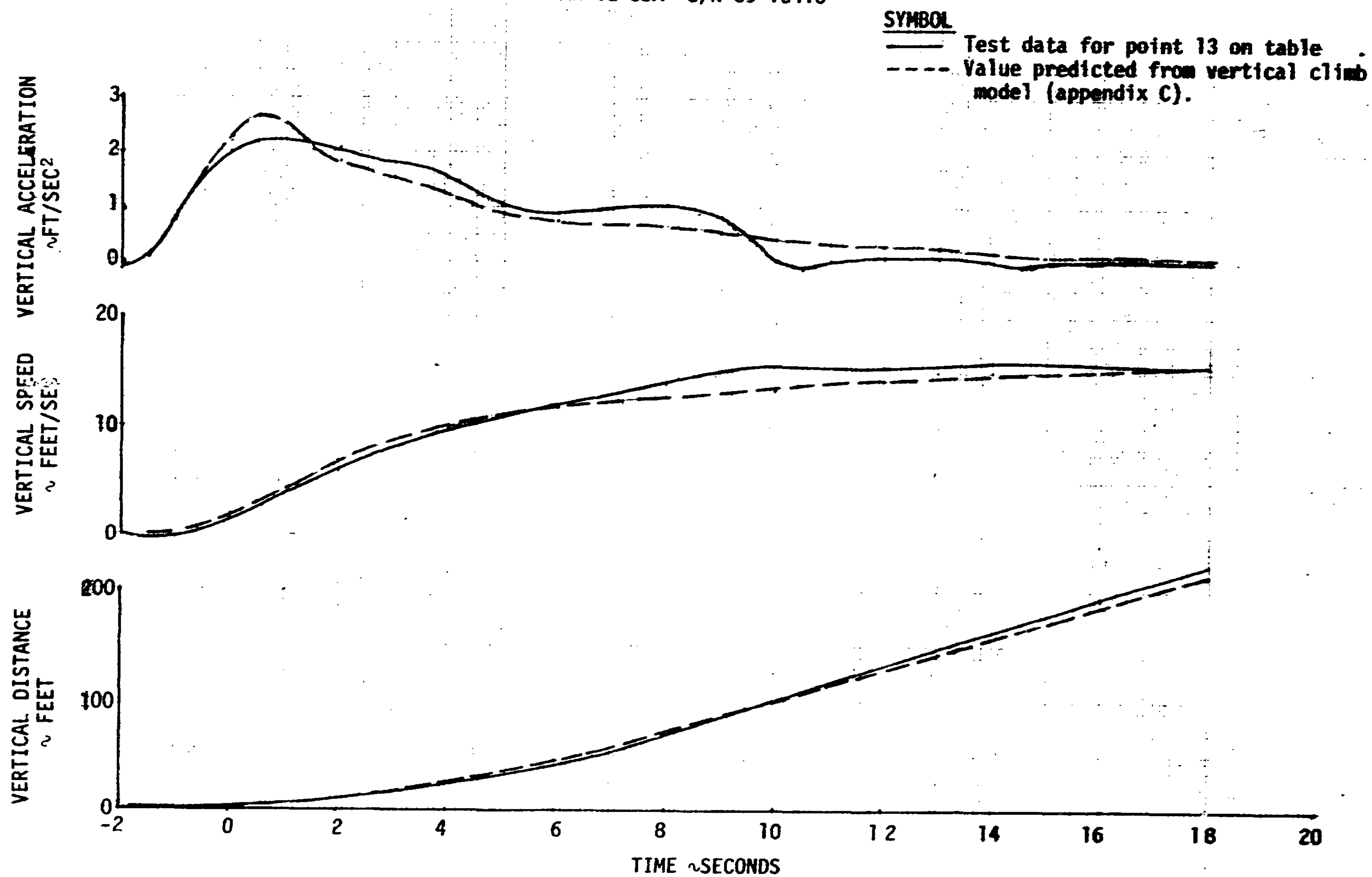


Table 3. Evaluation of Vertical Climb Testing.

Disadvantages	Advantages	Proposed Improvements
• Extended time spent in the avoid area of the H-V curve • Accurate space positioning equipment repaired • Uncertainty of measurement of atmospheric conditions • Low accuracy of measurement of power conditions • Changing rotor performance with rate of climb • Changing engine performance with rate of climb • Testing is accomplished in only a small portion of the vertical climb envelope • Low flight productivity • Difficult pilot tasks • Power and energy corrections are very complex	• Most closely resembles the vertical climb requirement • Theory can be used to check the test results • A nonturbulent wind of less than 3 knots has negligible effect on test results	• Develop low-airspeed measuring equipment to show pilot the relative airspeed • Develop better means of measuring power • Utilize more accurate space positioning equipment • Develop methods for power and energy correction

DIRECTIONAL CONTROLLABILITY CRITERIA

Free Hover

24. The AVSCOM recommendation (ref 2, app A) to measure performance margin in terms of yaw capability was evaluated with the aircraft in an OGE 500-foot free flight hover and in an OGE 50-foot tethered hover. In free flight hover conditions there is not sufficient flight information for the pilot to precisely stabilize the aircraft about all axes. Using ground references and tethered balloons requires that the pilot devote his attention ouside the cockpit, which complicates stabilizing the engine parameters. Atmospheric variations were very apparent in terms of pilot workload and introduced continual small variations about the hover point. A suitable airspeed reference would allow the pilot to maintain zero airspeed and drift with the wind. However, this drift would complicate obtaining vertical displacement from existing space positioning systems.

25. The results of the free flight yaw tests are shown in figure F. The yaw criteria is that the aircraft achieve an attitude change of 16 degrees at the end of 1 second. The power required for this maneuver was about 130 eshp and the pilot used approximately 1 inch of directional control. The scatter in the data is due to the uncertainty of power and attitude measurement. Power required was the difference between the measured power in the hover and the measured power during pedal input. The ±20 eshp scatter is within the accuracy expected of the measuring system as discussed in appendix C, and is typical of that experienced during hover performance testing.

Tethered Hover

26. The tethered hover results are presented in figure G. The peak engine power required for a 1-inch left pedal input (the amount required to achieve 16 degrees in 1 second) was 126 eshp, which agrees well with that obtained during the free flight hover tests. There was no height gain because of the restraining cable or any height loss because of the cable tension. The change in cable tension was random and varied approximately ±70 pounds. This is equivalent to about ±8 eshp in a hover.

FIGURE 7
DIRECTIONAL CONTROLLABILITY IN FREE FLIGHT HOVER
AH-1G USA S/N 69-16910

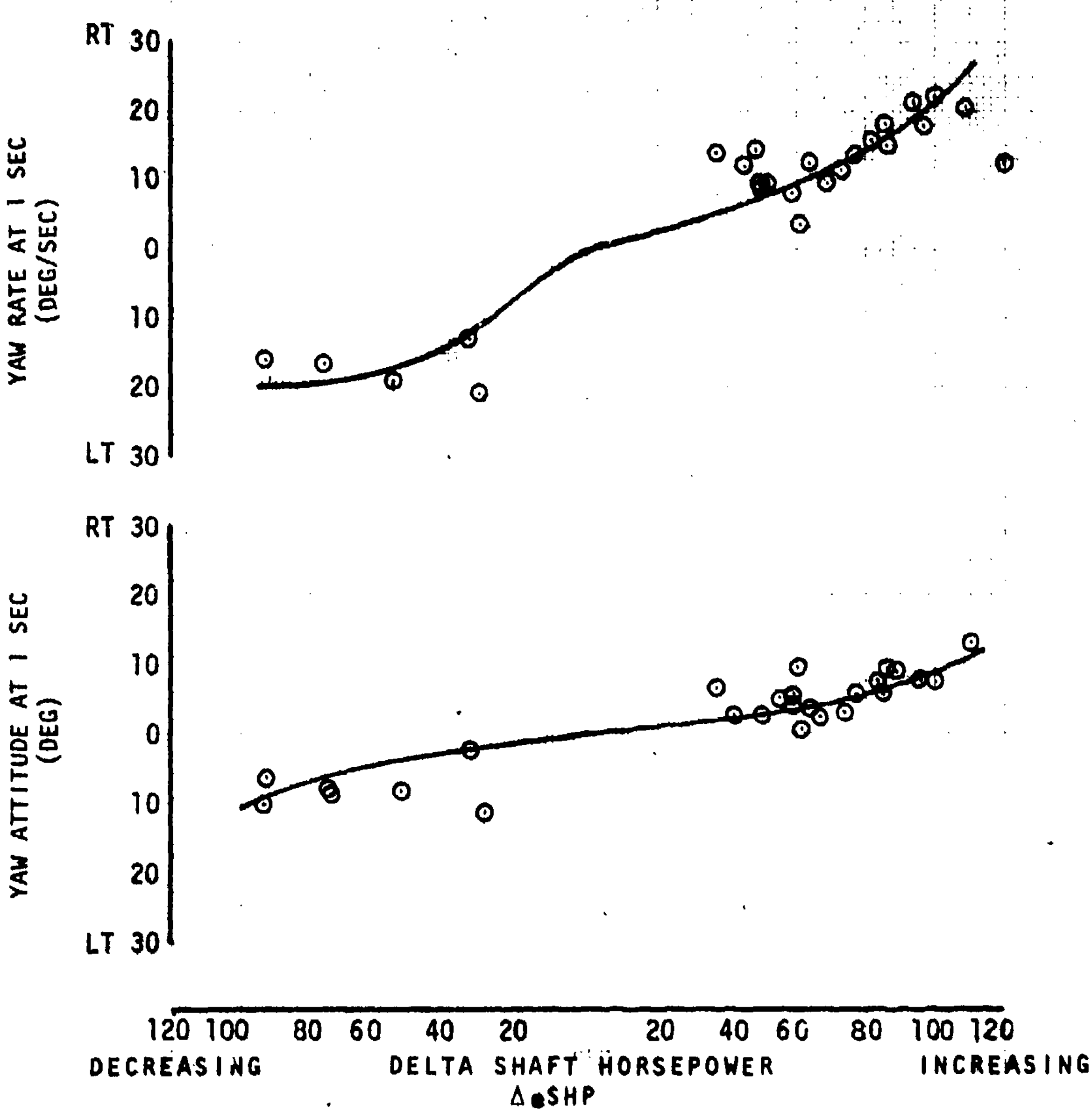
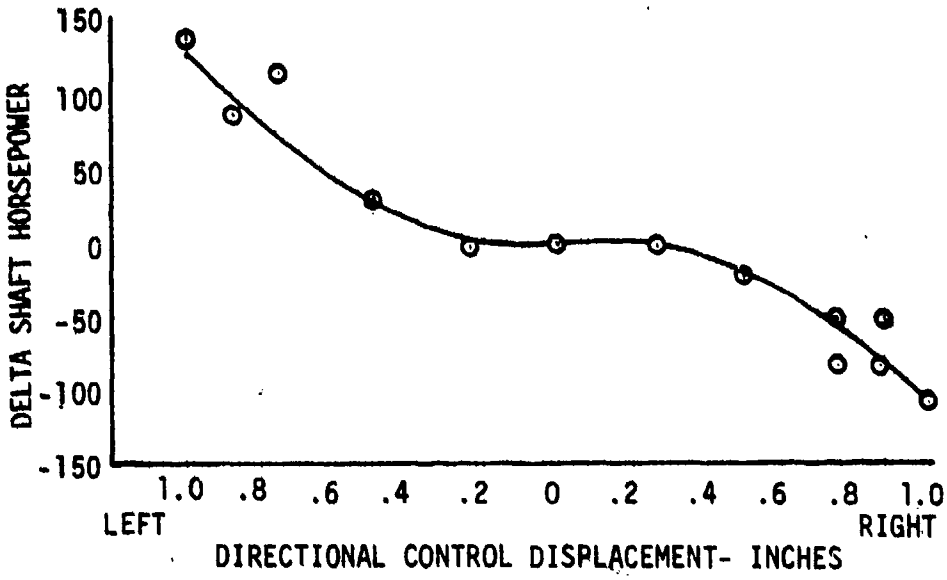


FIGURE G
TETHERED TURNS IN A HOVER
AH-1G USA S/N 69-16910



27. The tethered hover could be accomplished more easily and allowed greater control and/or measurement of the test conditions. The pilot could easily stabilize over a spot and the cable prevented vertical motion. Setting a cable tension allowed easy determination of thrust changes. Since the cable restricts translation over the ground, any horizontal velocity component is from the existing wind. When the winds are greater than 2 to 3 knots, the test should not be conducted, for the same reasons discussed in paragraph 18. The wind conditions can be more accurately measured for the lower skid height. The lower pilot workload and better control of flight parameters allows a much greater productivity than during free flight hover. The pedal input was only held a few seconds and there was little translation or change in cable angle.

28. The tail rotor thrust required for directional control was calculated by the AVSCOM method shown in reference 2, appendix A, and using previous hover test data from reference 9.

From:

$$\Delta T_{tr} = \frac{B^2 I_{z\psi}}{(e^{-B} + B-1) l_{tr}}$$

Where:

$B = 27\ I_Z^{-0.3}$.

I_Z - Yaw axis moment of inertia = 7626.32 slug-ft^2.

ψ - Yaw attitude change at 1 second = 16 degrees.

l_{tr} - Distance of tail rotor shaft from main rotor shaft.

Then, tail rotor thrust increase:

$$\Delta T_{tr} = 272 \text{ lb.}$$

The tail rotor power was then calculated from the thrust coefficient as follows:

$$C_{T_{mr}} = \frac{GW}{\rho A(\Omega R)^2} = 41.06 \times 10^{-4}$$

Where:

GW = 7500 lb.

ρ = 21.56 x 10^{-4} lb-sec^2/ft^4.

A = 1520.5 ft^2.

Ω = 33.93 rad/sec.

using figure 7, reference 9, the tail rotor thrust coefficient at a main rotor thrust coefficient of 41.06 x 10^{-4} is:

$$C_{T_{tr}} = 70.0 \times 10^{-4}$$

The delta tail rotor thrust coefficient for a 16 degree yaw displacement in 1 second is then determined from T_{tr} as follows:

$$\Delta C_{T_{tr}} = \frac{\Delta T_{tr}}{\rho A (\Omega R)^2}$$

Where:

$A = 56.74\ ft^2.$

$R = 4.25\ ft.$

$\Omega = 173.04\ rad/sec.$

$\Delta C_{T_{tr}} = 41.0 \times 10^{-4}$

Utilizing figure 12, reference 9, a delta Cp_{tr} for the maneuver is determined from ΔCT_{tr} by utilizing the portion of the tail rotor C_T/C_P curve above a CT_{tr} of 70.0×10^{-4}.

$\Delta C_{P_{tr}} = 9.6 \times 10^{-4}$

which is used to determine Δshp_{tr} as follows:

$$\Delta SHP_{tr} = \frac{\Delta C_{P_{tr}}\ \rho A (\Omega R)^3}{550}$$

$\Delta SHP_{tr} = 85.20$

29. The test data were not corrected for potential or kinetic energy changes during the maneuver. Also, in the calculation the tail rotor power values from reference 9, were obtained by extrapolating beyond the majority of the test data and power required could be considerably higher if the relationship becomes more nonlinear than shown.

Recommended Test Techniques for Directional Control Criterion

30. Table 4 presents the various aspects of directional controllability testing. The following test technique is recommended based on experience gained during the directional maneuverability portion of this test program.

a. Test aircraft should be at the specified rotor thrust and yaw axis moment of inertia configuration.

Table 4. Evaluation of Directional Controllability Testing.

Technique	Disadvantages	Advantages	Proposed Improvements
Free Flight Hover	• Accurate space positioning equipment required • Uncertainty of measurement of atmospheric conditions • Low accuracy of measurement of power conditions • Low flight productivity • Difficult pilot tasks • Power and energy corrections are very complex • Pilot does not have airspeed or vertical speed instruments to establish hover condition • Pilot must accomplish the maneuver in a very limited airspace • Measurement of yaw attitude changes • Yaw moment of inertia must be closely controlled for valid yaw results • Results cannot accurately be confirmed with calculations	• Maneuver is accomplished outside the avoid area of the H-V curve • Short time period of the maneuver minimizes the dynamic aspects of the maneuver • The test could be accomplished in a nonturbulent wind of less than 3 knots • Provides data concerning tail rotor performance	• Develop airspeed and vertical speed to assist the pilot • Develop better means of measuring power • Utilize more accurate space positioning equipment • Develop methods for power and energy corrections • Develop better attitude measuring system
Tethered Hover	• Extended time spent in the avoid area of the H-V curve • Low accuracy of measurement of power conditions • Power and energy corrections must be made • May not simulate free flight environment with respect to power required to yaw • Measurement of yaw attitude changes are difficult • Yaw moment of inertia must be closely controlled for valid yaw results • Pilot does not have airspeed or vertical speed instruments to establish hover condition • Very low wind conditions are required for the test • Results cannot accurately be confirmed with calculations	• Provides data concerning tail rotor performance • Short time period of the maneuver minimizes the dynamic aspects of the maneuvers • Pilot task is not overly difficult • The tether cable prevents height changes • The atmospheric conditions can be measured easily and accurately • Cable tension can be used to simulate cross weight • Energy and power corrections are simplified • A high flight productivity can be achieved • Minimum ground support and equipment is required • Provides data concerning pilot workload when hovering in winds	• Develop better means of measuring power • Develop methods for power and energy corrections • Develop better attitude measuring systems • Develop better thrust measuring equipment

b. The engine power to produce the directional control required should be demonstrated in a tethered hover.

c. Energy losses and power variations should be accounted for as shown in Appendix B.

SAFETY

31. Any new test method must be considered in terms of potential hazard, degree of exposure, and emergency procedures. The vertical climb and OGE tethered hover tests require that the aircraft be operated in the "avoid" area of the height-velocity curve.

ATMOSPHERIC CONSIDERATIONS

32. The effect of atmospheric conditions on performance is a function of temperature and pressure. Since it is unlikely that any Army hot day specification can be exactly duplicated at test locations, the thrust coefficient (C_T) and tip mach number (M_{tip}) corresponding to the test aircraft design gross weight at the hot day condition will be the aim C_T and M_{tip} for testing in atmospheric conditions other than hot day. Provided test aircraft structural and/or rotor speed limits are not exceeded, constant C_T and M_{tip} may be flown in existing atmospheric conditions by varying gross weight and rotor speed.

CONCLUSIONS

GENERAL

33. Vertical climb performance is difficult to obtain directly from flight tests. Instrumentation accuracy, atmospheric conditions, and the pilot's ability to climb vertically combine to produce data scatter. The simplest and most accurate technique is to calculate vertical climb capability from hover performance data obtained during tethered hover tests and adjusted momentum theory. Energy corrections must be used to improve the measured data. Vertical climbs at selected conditions should be flown under ideal weather conditions for vertification of the derived performance.

34. Directional controllability tests were easily performed in tethered hover. However, considerable analysis and corrections are necessary to account for aircraft and rotor transients. The power requirements for the controllability criterion were not accurately predicted by theory, even though empirical tail rotor data were available.

SPECIFIC CONCLUSIONS

35. The pilots can conduct vertical climb performance tests within allowable deviations from the vertical (para 19).

36. The vertical climb test results were improved by corrections for rotor speed deviations and unsteady flight conditions (para 20).

37. Momentum theory agreed well with climb performance results for vertical speeds up to 500 ft/min (para 21).

38. A model was developed which used hover power required and momentum theory to predict transient vertical climb performance with an accuracy comparable to that which can be attained in flight tests (para 22).

39. For the AH-1G helicopter, more power is required on a transient basis to meet the proposed directional controllability criterion than is necessary to conform with the 500 ft/min VROC criteria (paras 21 and 25).

40. Power required resulting from the AH-1G yaw maneuverability tests did not agree well with calculations based on tail rotor performance data and the method in the AVSCOM Army hot day design study (para 26).

41. Accuracy of power measurement and rate-of-climb determination introduced an uncertainty of ±240 ft/min in the AH-1G vertical climb performance results (para 20 and app C).

42. Instrumentation such as radar or radio altimeters, low-airspeed sensor, magnetostrictive torque transducers, and improved yaw attitude gyros should increase the accuracy of vertical climb or yaw maneuverability test results (paras 23, 30, and app C).

43. The space positioning equipment used did not have sufficient accuracy and resolution to measure small transient aircraft motions (para 7, app C).

RECOMMENDATIONS

44. Improve capability to measure power required, yaw attitude displacement, aircraft position and motion, and atmospheric conditions.

45. Develop improved correction methods to account for energy losses and transfers during vertical climbs and yaw maneuvers.

46. Use hover performance test data and adjusted momentum theory to determine compliance with the vertical climb criteria. The momentum theory adjusment may include a VROC power correction factor to be determined from test data on each configuration of interest.

47. Future VROC performance tests should be flown at constant referred or nondimensional test conditions to simplify data reduction and parameter extrapolation.

APPENDIX A. REFERENCES

1. Final Report, United States Army Combat Developments Command, *Vertical Flight Performance Criteria*, January 1968.

2. Final Report, AVSCOM, ADS TN 68-1, *A Study of the Army Hot Day Design Hover Criteria*, August 1970.

3. Letter, Department of the Army, AGAM-P, 29 October 1968, subject: Hot Day Hover Criteria For Army VTOL Aircraft.

4. Military Specification, MIL-H-8501A, *Helicopter Flying and Ground Handling Qualities; General Requirements for*, 7 September 1961, amended 3 April 1962.

5. Letter, AVSCOM, AMSAV-R-F, 9 November 1968, subject: Flight Test Techniques for Determining Compliance with Performance Guarantees for New Army Hovering Criteria.

6. Letter Report, USAASTA, February 1970, *Evaluation of Flight Test Techniques to Determine Compliance with Various Hot Day Hovering Performance Guarantees*, Project No. 68-55.

7. Letter, AVSCOM, AMSAV-R-F, 27 November 1970, subject: Evaluation of Flight Test Techniques to Determine Compliance with Various Hot Day Hovering Performance Guarantees, Project No. 68-55.

8. Test Plan, USAASTA, Project No. 68-55, *Vertical Climb Program*, February 1970.

9. Final Report, USAASTA, Project No. 66-06, *Engineering Flight Test AH-1G Helicopter (Hueycobra)*, April 1970.

10. Textbook, A. Gesow and G. Meyers, *Aerodynamics of the Helicopter*, Frederick Ungar Publishing Company, New York, 1967.

11. Textbook, Naval Test Pilot School, USNTPS-T-NO1, *Principles of Helicopter Performance*, 8 March 1968.

APPENDIX B.

ENERGY CORRECTIONS AND ANALYSIS OF VERTICAL CLIMB MANEUVERS

GENERAL

1. This appendix contains the derivation of equations required to calculate energy corrections to nonsteady flight conditions and vertical climb performance from momentum analysis. The derivation of a simple one-dimensional vertical climb model based on the momentum equations is also discussed.

ENERGY CORRECTIONS

2. A general power-energy equation for nonsteady flight conditions may be obtained by adding helicopter and rotor acceleration terms to the classical level flight power equation derived in reference 10, appendix A, as shown in equation 1.

$$P = P_i + P_o + P_p + V_v GW + M(A \bullet V) + I_r \Omega \dot{\Omega} \qquad (1)$$

Where:

P = Total rotor power required	ft-lb/sec
P_i = Induced power	ft-lb/sec
P_o = Profile power	ft-lb/sec
P_p = Parasite power	ft-lb/sec
V_v = Vertical velocity	ft/sec
GW = Gross weight	lb
M = Mass	slugs
A = Aircraft acceleration	ft/sec^2
V = Aircraft velocity	ft/sec
I_r = Rotor moment inertia	slug-ft^2
Ω = Rotor angular velocity	rad/sec
$\dot{\Omega}$ = Rotor angular acceleration	rad/sec^2

Corrections for aircraft angular accelerations were assumed to be negligible for the vertical climb tests. Also, the P_o term is considered to include tail rotor, transmission, and, accessory power requirements in addition to the main rotor profile power.

3. The excess power required to generate a given VROC (P_{ex}) can be defined as the difference between the power required in a hover (P_h) and the power required in the vertical climb (P_c). This relationship is shown in equation 2.

$$P_{ex} = P_c - P_h \qquad (2)$$

In a hover the potential, kinetic, and rotor energy terms should be zero. However, it was difficult to obtain stabilized hover conditions prior to initiating the vertical climb tests. Therefore, the P_h term was corrected to a hover condition by removing the energy terms from the measured power (P_m), as shown in equation 3. Additionally, equation 3 can be used to correct P_c data for any linear or rotor speed acceleration which may be present in the final vertical climb condition by deleting the potential energy change term ($V_v \cdot GW$).

$$P_h = P_m - (I\Omega\dot{\Omega} + V_v GW + M(A \bullet V)) \qquad (3)$$

4. Energy corrections were not applied to the maneuverability test results. However, the power required to achieve the specified angular displacement in 1 second following control input should be corrected for the nonsteady power terms shown in equation 1. Ideally, the maneuverability test should be flown with no change in altitude, rotor speed, or cable tension (when tethered). The loss of altitude or rotor speed would add to the power required to perform the maneuver and must be accounted for to determine a correct excess engine power available. First, the hover power must be corrected for any unsteadiness, as discussed in paragraph 2. Then, the measured power during the maneuver should be corrected for any power change not related to achieving the specified yaw displacement. This corrected power required to yaw is also determined as shown in equation 3.

5. For tethered hover tests, power corrections also have to be made for any significant variation in cable tension. The change in cable tension is used to correct the thrust. Nondimensional hover performance data are then used to obtain the corrected power coefficient from which the power is calculated.

VERTICAL CLIMB PERFORMANCE

6. In the past, the climb performance of helicopters has been related to the rate of change of potential energy by determining a power correction factor (K_p), as shown in equation 4.

$$K_p = \frac{\Delta V_v}{\Delta P} \times \frac{GW}{550} \qquad (4)$$

This factor has been used with varying degrees of success for helicopters in forward flight conditions. It was suggested in reference 8, appendix A, that this method could also be used for vertical climb analysis. However, K_p will be a function of both the rate of climb and C_T and is undesirable for use in vertical climb analysis.

7. Momentum analysis allows for the variation of induced power (P_i) due to the increased inflow caused by the vertical climb velocity. Vertical climb equations have been derived in references 10 and 11, appendix A, and are considered to be accurate for moderate rates of climb. The method used to derive workable equations combines energy relations with momentum analysis to allow for the variation of induced power (P_i) with vertical speed. The method assumes that other power requirements remain constant and are combined in one power (P_t) term and determined from equation 5.

$$P_t = P_h - P_i = (P_o + P_p + I\Omega\dot{\Omega} + M(A\bullet V)) \tag{5}$$

Where:

$I\Omega\dot{\Omega} = M(V.A) =$ zero for steady flight conditions.

The induced power variation in climb can then be determined by calculating the induced velocity in climb (ν_v) from equation 6. The derivation of equations 6 and 7 is provided in reference 10, appendix A.

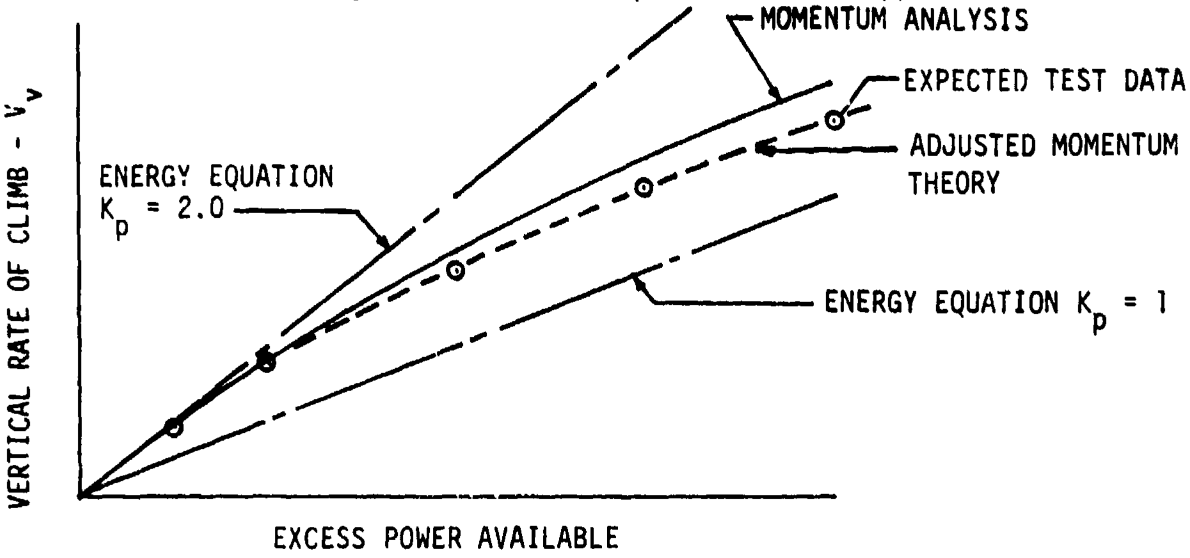
$$\nu_v = \frac{-V_v + \sqrt{V_v^{\,2} + 2\,C_t\,(\Omega R)^2}}{2} \tag{6}$$

The power required in climb can then be determined from the main rotor thrust and gross weight, as shown in equation 7.

$$P_c = T\nu_v + GW\,V_v + P_t \tag{7}$$

8. Typical VROC power variation from both energy and momentum analysis (ref 11, app A) is shown in figure 1. This figure shows that K_p varies with vertical speed and considerable test data would be required to obtain the K_p for each configuration of interest. The basic momentum analysis becomes optimistic above a VROC of 500 to 800 ft/min (ref 10) because of the increased fuselage drag and the other power terms comprising P_t (equation 5). Therefore, the basic momentum equations require adjustment to match the test data.

Figure 1. Variation of Vertical Climb Rate with Excess Power Available (reference 11, app A)



9. The adjusted climb power can be calculated by adding terms for parasite power (P_p) and increased profile power (P_o) to equation 7, as shown below. The parasite power may be added as a function of V_v only because vertical drag is already included in the hover power. This term is small at low climb rates, but adds a second-order velocity term which helps to linearize the remaining error source. The remaining power difference (P_{o_c}) can be plotted from test data in terms of P_{o_c}/P_{o_h} and the vertical advance ratio ($V_v/\Omega R$) to nondimensionalize the parameters, as shown in figure 2. The slope of this data line may then be used as the VROC power correction factor (K_c) as shown in equation 8. The slope may also vary with average gross weight, which should be determined from test data at various weights.

$$P_c = TV_v + GW\, V_v + P_p + P_{oh} \left(1 + K_c \frac{V_v}{\Omega R}\right) \qquad (8)$$

Where:

$T = GW + 1/2 \rho V_v^2 A_z$

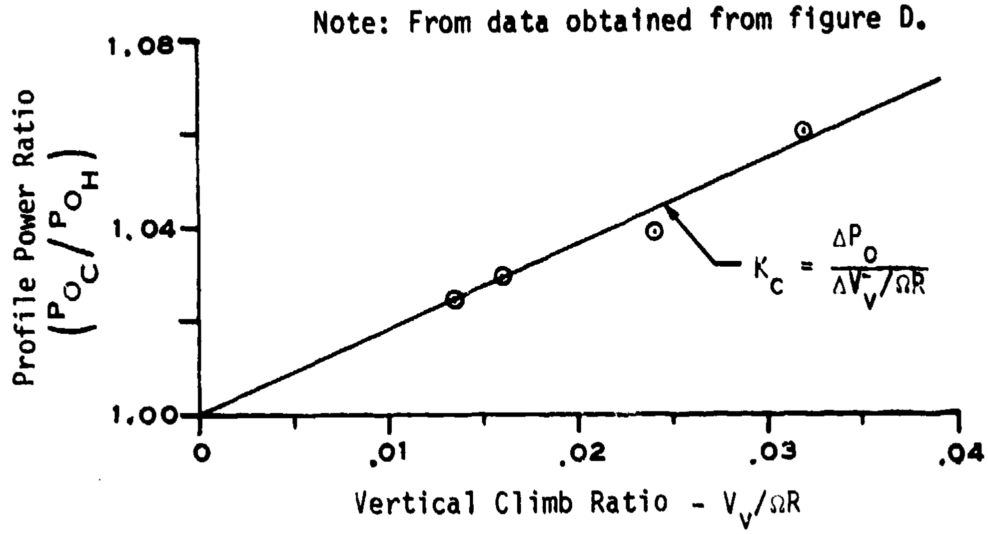
$P_p = 1/2 \rho V_v^3 A_z$

A_z = Estimated fuselage flat plate area in vertical axis-ft^2.

ρ = Ambient air density - slug/ft^3.

K_c = VROC power correction factor as defined in figure 2.

Figure 2. Profile Power Variation in Vertical Climb
AH-1G USA S/N 69-16410



Vertical Climb Model

10. The tethered hover data may also be input into a simple computerized vertical climb model which can calculate the VROC and flight path as a function of time during the acceleration to the steady climb condition. The program computes the flight path from the parameters shown in figure 3. In free flight conditions, the parameters actually vary as shown by the solid lines, since power and thrust cannot build up instantaneously. This delay time has been built into the model and can be determined from flight data. The data obtained from test flights indicate that the delay was 2 to 3 seconds. However, the final velocity computed by the model is only dependent on P_{ex} and variation of thrust profile has no effect on final velocity.

11. To drive the model, a relationship between excess thrust and power was obtained from the nondimensional parameters shown in figure 4. The coefficients are calculated as shown in equations 9 and 10 and their relationship is provided in equation 11.

$$C_{t_{ex}} = T_{ex}/\pi R^2 \rho (\Omega R)^2 \quad (9)$$

$$C_{P_{ex}} = P_{ex}/\pi R^2 \rho (\Omega R)^3 \quad (10)$$

$$C_{t_{ex}} = \left(\frac{C_{P_{ex}}}{m}\right)^{2/3} \quad (11)$$

Figure 3. Typical Parameter Variation
During Vertical Climb Test Point

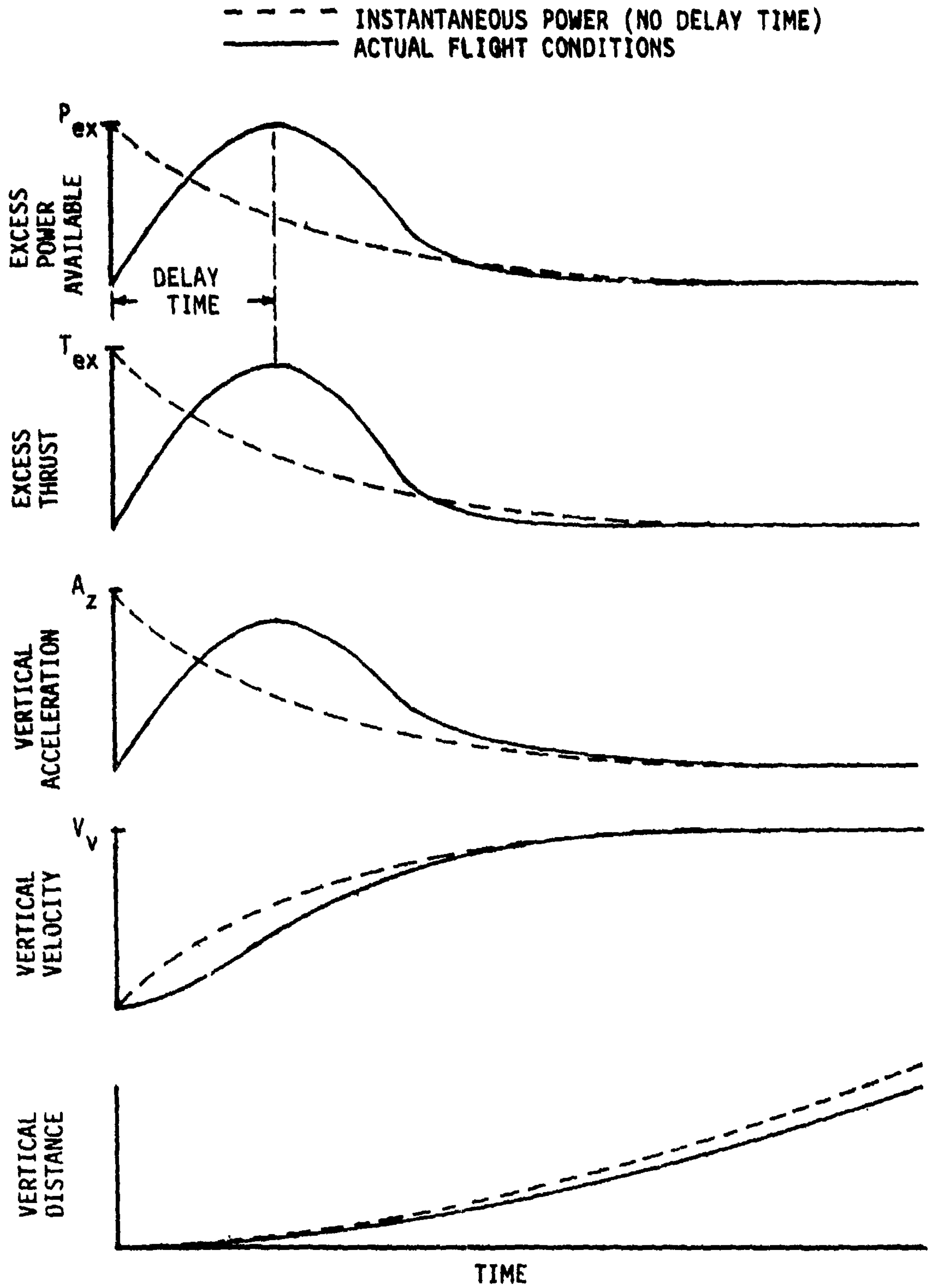
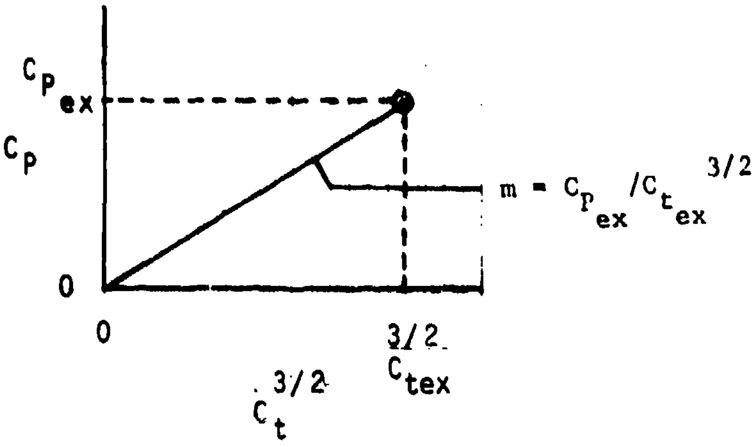


Figure 4. Nondimensional Hover Performance Point



12. A loop for calculating the flight path parameters was then established until the excess power was absorbed by the rate of climb and the aircraft is no longer accelerating as shown in figure 3. The necessary equations for calculating thrust, acceleration, velocity, and distance are shown below.

$$T_{ex} = C_{t_{ex}} * (\pi R^2 \rho (\Omega R)^2) \tag{12}$$

$$A_z = \frac{T_{ex}}{Mass} \tag{13}$$

$$V_v = \int A_z \, d_t \tag{14}$$

$$Z = \int V_v \, d_t \tag{15}$$

13. At each point, the induced velocity in climb can be calculated from equation 6, allowing the calculation of the vertical climb power in equation 7. The excess power would then be decreased by the climb power required and the power required for vertical acceleration as shown in equation 16.

$$P_{ex} = P_m - P_c - M(A_z \cdot V_v) \tag{16}$$

The program then loops back to equation 9 to determine the modified thrust until P_{ex} converges. When convergence occurs, the time is incremented by a delta time

(ΔT) and calculations for the next point begin again at equation 7. The integration of acceleration and velocity would continue until P_{ex} is zero, which would simulate the steady rate of climb condition. Therefore, the model simulation provides both the time and flight profile required to achieve the final rate of climb.

APPENDIX C. DATA ACQUISITION

GENERAL

1. The instrumentation and data acquisition methods used during this evaluation are presented in this appendix. The equipment used did not possess sufficient accuracy in engine power and space positioning measurement to produce completely repeatable data. This nonrepeatability or data scatter during vertical climbs and hover testing is partially a product of aircraft nonvertical motion and primarily inaccuracies in engine power determination. Energy dissipated in the form of aircraft nonvertical motion was corrected for and reduced the data scatter. Appendix B shows the necessary energy corrections applied to the vertical flight and maneuverability test data.

SHAFT HORSEPOWER

2. Engine output shaft power in these tests was calculated from measured values of output shaft torque and power turbine speed. The standard engine differential torque pressure output was used. Estimates of the uncertainty of this type of torquemeter range from ±1 percent full scale to ±15 percent full scale under steady-state conditions. Engine manufacturer specifications claim that each engine torquemeter shall indicate actual torque developed within ±2.0 percent of the engine torque curve defined by the engine data plate torque constant. This simply means that specified torque is supposed to be within ±2 percent of reading under steady-state conditions. Several studies demonstrate this tolerance is optimistic.

3. Published data on the hydromechanical torquemeter performance under transient conditions, such as those encountered in the maneuverability test, are not available and it can only be assumed that additional uncertainty will be introduced by the unknown response characteristics (time lags and possibly overshooting). Accepting the 2-percent tolerance, additional torque error is still introduced by the equipment used to read torque pressure. Instrument panel indicators and oscillograph data such as that obtained during these tests will introduce an error of approximately ±1 percent full scale. At a typical power setting of 1000 shp then, the combination of errors results in an uncertainty of about 30 shp due to torque measurement only. It should be noted that improved transducers have reduced pressure reading error to a negligible value in current tests. The turbine speed measurements used during this test provided true speed to ±0.4 percent of reading, which is not a significant error contribution. This accuracy can be improved to ±0.1 percent with current equipment. There is no indication at present that engine torque measurements better than ±1 percent of reading are to be expected.

THRUST MEASUREMENTS

4. Total thrust measurements in tethered hover can be made with a low level of uncertainty with current instrumentation. A modern strain gauge load link in series with the restraining cable can yield cable thrust components having uncertainties as low as ±0.15 percent full scale with good calibrations and a high quality recording system. For UH-1 or AH-1 type helicopters, using a full scale of approximately 4000 pounds, tether thrust components are as good as ±6 pounds. Measurements of aircraft gross weight, the other component of thrust in OGE tethered hover, are the limiting factor on thrust accuracy in current tests. Standard Army three-point strain gauge load cell weight and balance kits are used for initial empty weights. The kit in use for medium weight helicopters can yield gross weight errors as small as ±20 pounds. More modern equipment could reduce this error by a factor of four.

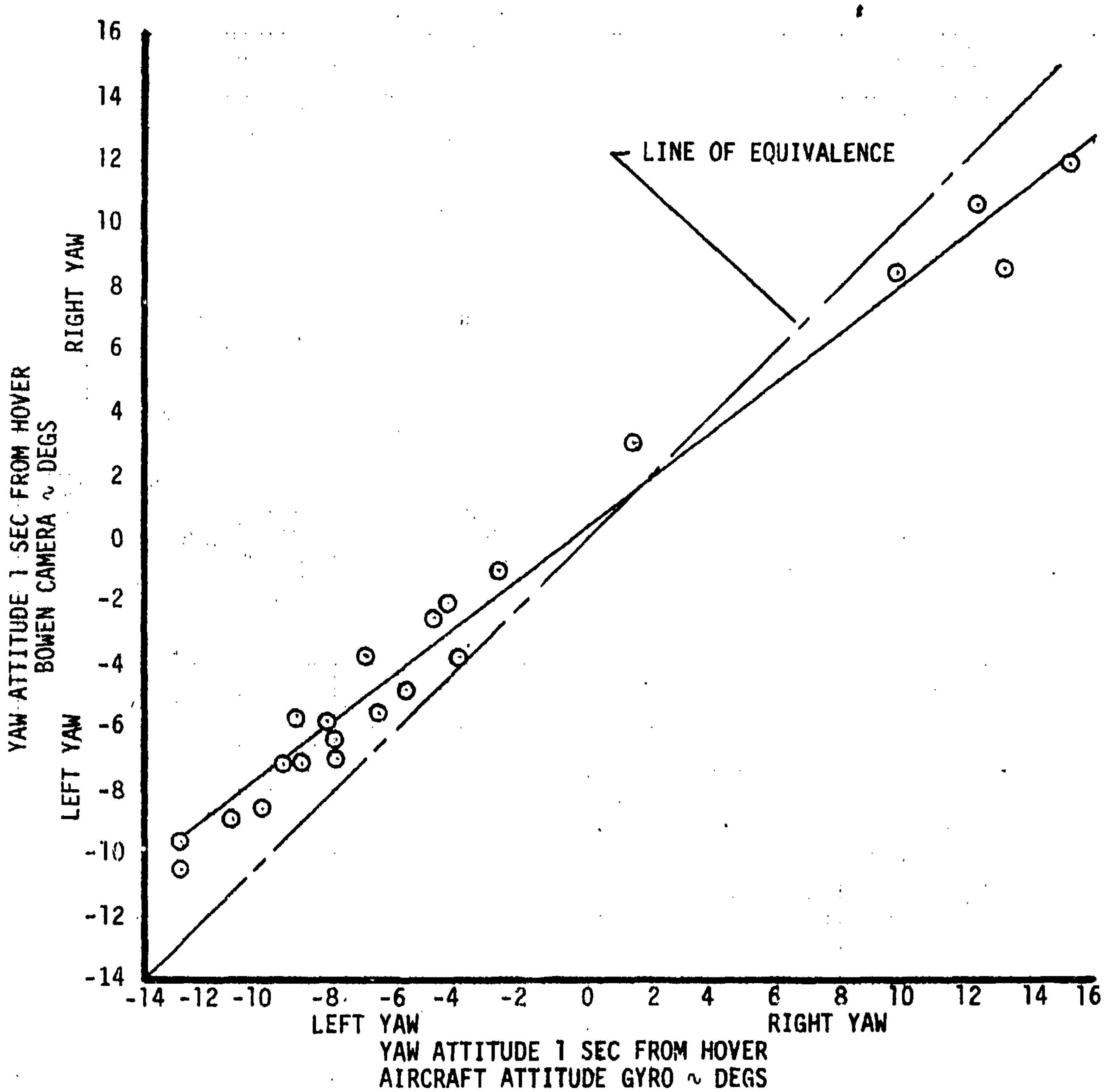
5. Daily fuel loading can be monitored with a tolerance of about ±10 pounds, using calibrated fuel tanks and daily specific gravity checks. If a good turbine flowmeter is combined with fuel temperature measurements or in-line densitometer readings, then errors in recording fuel burnoff have a negligible effect on the tethered thrust values.

6. Converting these numbers to equivalent full scale errors on a 6000-pound helicopter and doing a root-sum-square combination, the total thrust can be measured with a tolerance of 0.4 percent.

YAW DISPLACEMENT

7. Attitude data were obtained independently from the space positioning equipment and from the gyros aboard the aircraft. The comparison in figure 1 shows that the attitude change from the Bowen cameras is consistently less than from the attitude gyros. The difference becomes greater with greater yaw and is about 3 degrees as a yaw change of 16 degrees in 1 second. Errors in space positioning data are usually in two categories. Equipment alignment or location, tracking procedure, or images not being in true size, can produce erroneous data. Size of image, accuracy of reading, and wrong constants usually produce errors in the data processing. The increasing error with yaw rate would suggest a timing or tracking error.

FIGURE 11
COMPARISON OF YAW ATTITUDE DATA FROM BOWEN CAMERA AND ATTITUDE GYRO INSTALLATION
AH-1G USA S/N 69-16510



8. Tests at the NWC utilized a precision two-gimbal vertical gyro modified for use as a two-gimbal gageable free-directional gyro monitor yaw displacement. Gimbal position was measured by the output of a wirewound potentiometer. For the stabilized yaw displacement maneuver, basic gyro precision for a 30-second interval after gimbal release was ±0.5 degree for yaw rates lower than 30 degrees per second and small roll attitude perturbations. This statement includes the effects of repeatability, hysteresis, precession and drift rate. This figure was increased to ±0.75 degree by the stability and resolution of the signal conditioning and recording equipment used to record gimbal displacements. Nominal event signal recognition and oscillograph time base uncertainties were used for a final estimate that yaw displacement produced in 1 second could be determined with a precision of approximately ±1 degree.

9. The yaw attitude should be more accurate than the Bowen camera equipment. However, this 1-degree figure is not the only consideration. Data interpretation and pilot technique could add systematic errors and imprecision to the measured displacements that would greatly influence inferred estimates of excess power.

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